EMSolve

Computational Electromagnetics

Overview

Lawrence Livermore National Laboratory (LLNL) has long been recognized as a leader in the world of scientific computer simulations. Researchers are developing multidimensional models of the dynamic and complex forces at the atomic level, visualizing the processes at work in the birth and death of stars, and studying the effects of greenhouse gases on global climate and of pollutants in our environment. It is not surprising, then, that LLNL is a leading developer of computer codes that simulate propagation and interaction of electromagnetic (EM) fields.

Lawrence Livermore's EM field experts study and model wave phenomena covering almost the entire electromagnetic spectrum. Applications, as varied as the wavelengths of interest, include particle accelerator components, photonic and optoelectronic devices, aerospace and radar systems, and microwave and microelectronics devices.

A variety of computer codes for computational EM are currently under development at LLNL. Development of a modern EM code requires expertise in electromagnetic theory, applied mathematics, and computer science. These projects are often conducted in collaboration with other LLNL directorates, with university students and faculty, and with industry.

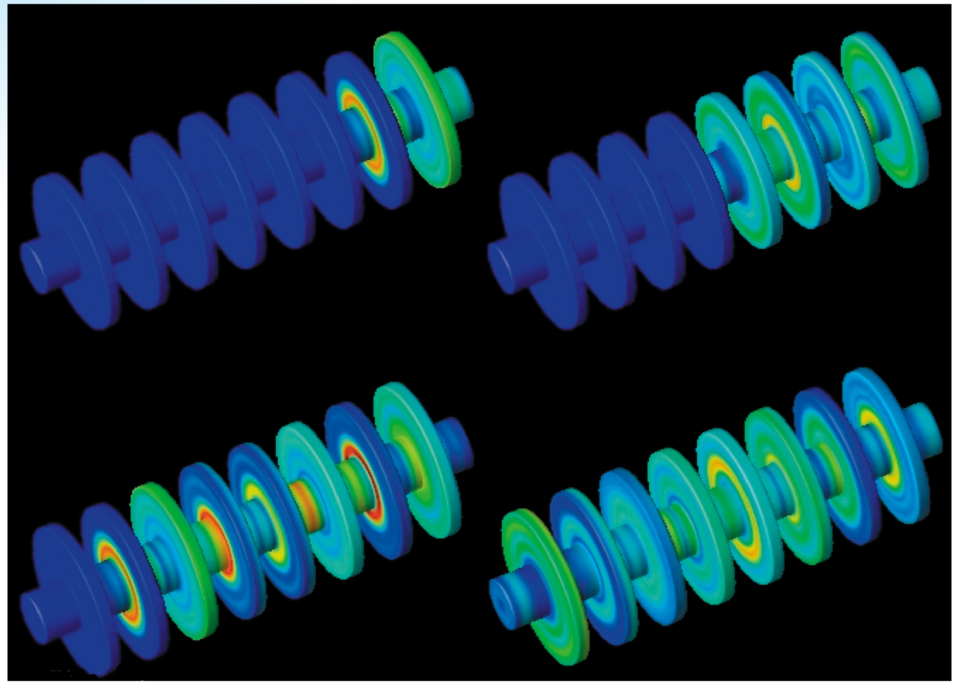

Figure 1. Transient simulation of accelerator wakefields computed using EMSolve. A relativistic Gaussian electron bunch propagates down the center of a series of induction cells, generating EM fields (the electromagnetic "wake") that persist for a very long time. Stable and non-dissipative methods are essential for quantitative prediction of EM wakefields.

Current Research Activities in Computational EM Include:

- Time-domain and frequency-domain methods
- Higher-order finite element basis functions
- Hybrid finite element–boundary element methods
- Hierarchical and adaptive methods
- Fast solvers for implicit equations
- Non-linear material models
- Photonics, IC interconnects, and substrate coupling effects
- Coupled EM, mechanical, thermal simulations
- Object-oriented frameworks for parallel computation

EMSolve

The EMSolve project started out as an effort to develop provably stable time integration methods for solving Maxwell's equations on 3D unstructured grids. We determined that late-time instabilities seen in finite-volume solutions of Maxwell's equations were caused not by the time integration method per se, but by improper discretization of the curl operator. We eventually tried a Galerkin discretization of Maxwell's equations using Nedelec's H(curl) and H(div) finite element basis functions for the E and B fields, respectively. This resulted in a provably stable, charge-conserving and energy-conserving solution of Maxwell's equations.

EMSolve currently supports several different types of finite element basis functions and several different differential operators. EMSolve can be used to solve a variety of PDEs such as Poisson's equation, div-curl systems, diffusion problems, wave equations, etc. EMSolve is written using a combination of Python and C++ and runs on PCs, SMP workstations, and distributed memory supercomputers.

The EMSolve software framework has been used for a variety of EM problems such as accelerator design, optical trapping of micro particles, and magnetohydrodynamics. Currently, the EMSolve team is researching higher-order "spectral" finite elements, fast solvers for implicit time-domain simulation, and the connection between finite element methods and differential forms.

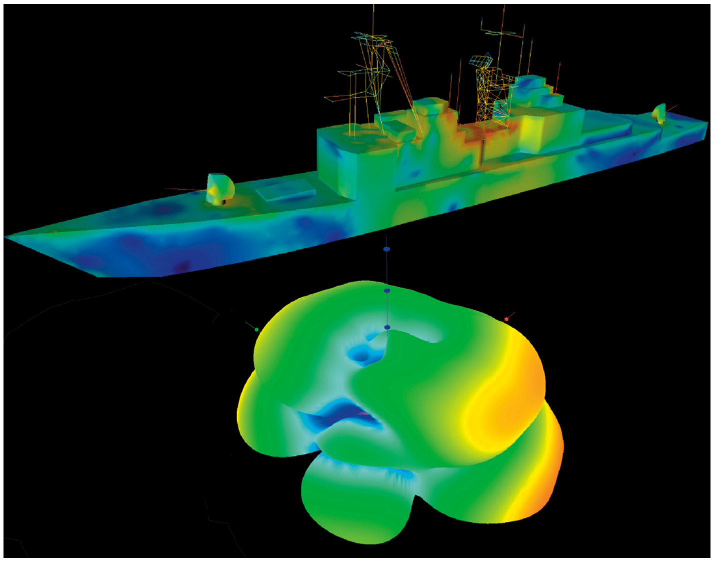

Figure 2. The installed performance of a communications antenna can be quite different than the free-space performance. EIGER has been used extensively by the DoD to quantitatively predict the installed performance of antennas in complicated environments, such as the destroyer shown above. The top image represents the magnitude of the surface current density induced by the antenna; the bottom image is the installed radiation pattern.

EIGER

The EIGER (Electromagnetic Interactions GEneRalized) development project is a multi-institutional collaboration that is bringing an unparalleled variety of spectral domain analysis methods into a single integrated software tool set. Project members include the Lawrence Livermore National Laboratory, the Sandia National Labs, the Navy (SPAWAR SSC), the University of Houston, and other leading universities.

New software engineering methods, such as object-oriented design, are being used to abstract the key components of spectral analysis methods so that the tools can be easily modified and extended to treat new classes of problems. This software design method yields a code suite that is more easily maintained and more compact than standard designs, where entire codes are developed around a single numerical method.

The EIGER suite currently employs higher-order numerical methods (for both geometry and basis functions) to solve hybrid boundary element (moment method) and finite element formulations. In addition, the boundary element solutions may employ a variety of Green's functions to efficiently model layered (stratified) media, periodic structures (e.g., phased arrays and frequency selective surfaces), and combinations of the two, in addition to the homogeneous medium treatments. The code suite can model 2D and 3D geometries composed of surface, wire, and volumetric elements. A variety of boundary conditions and symmetry operators are also available.

Recent applications are as diverse as modeling MEMs devices, the human neck (for speech recognition), microwave circuits, full-scale DoD systems (e.g., missile, ships, etc.), and phased arrays.

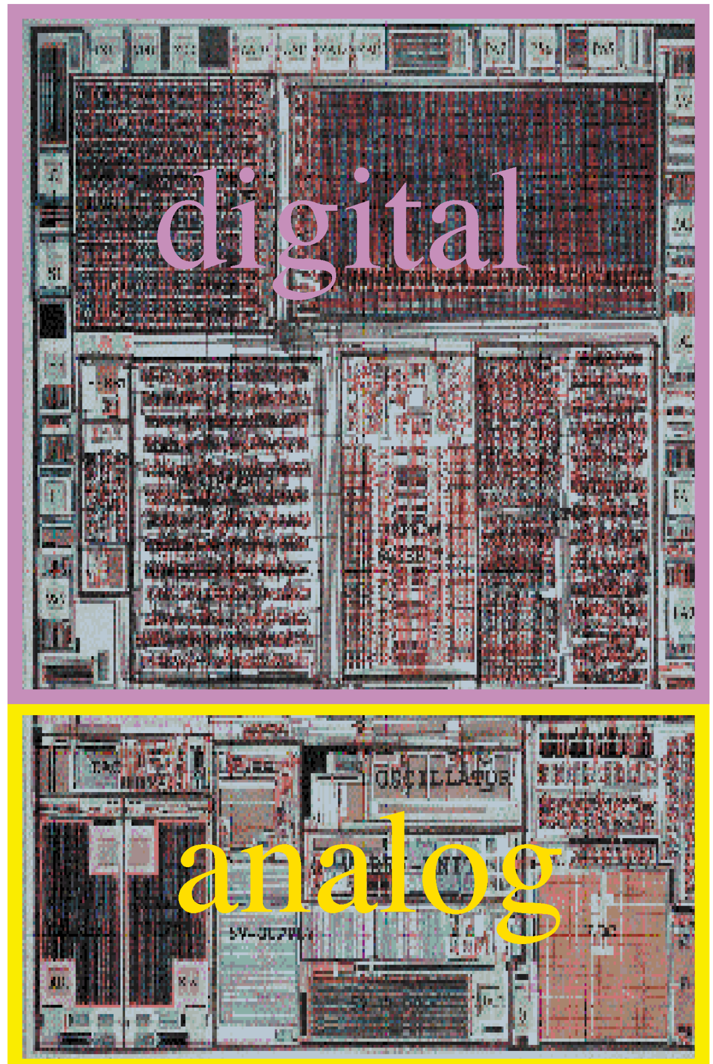

Figure 3. Mixed-signal "systems on a chip" have numerous applications in radar, telecommunications, robotics, biomedicine, etc. Switching noise generated by the digital section can interfere, perhaps catastrophically, with the sensitive analog section. LLNL engineers, in collaboration with University of Washington, are developing special-purpose simulation tools for rigorous analysis of EM coupling effects in IC's.

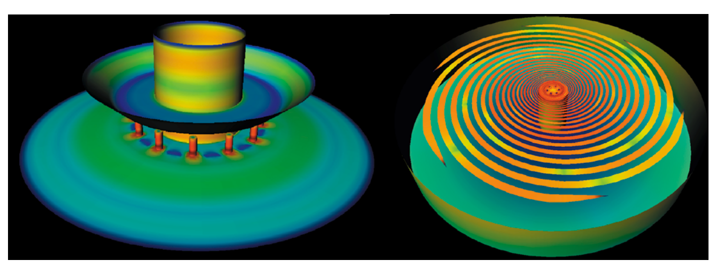

Figure 4. The EIGER code incorporates many special features for antenna design, such as periodic boundary conditions for phased arrays, special Green's functions for planar multilayer structures, and hybrid finite element – boundary element discretization. Both antenna models above both incorporate discrete rotational symmetry for efficiency.

For more information on this project, contact Dan White, (925)422-9870, dwhite@llnl.gov.

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